ECONOMIC EFFECTS OF ENFORCEMENT VARIABLES ON COMMERCIAL OIL POLLUTION CONTROL STRATEGY

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THESIS

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VARIABLES ON COMMERCIAL OIL
POLLUTION CONTROL STRATEGY

by

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I. INTRODUCTION

Concern over the potential effects of oil spills on the waters of the world has led to increasing efforts to analyze and control the problem. Emphasis has been placed on programs which offer improvements in the technology of oil spill removal and greater efficiency in enforcement and prevention measures. The concern is warranted. Some scientists estimate that about five million tons of petroleum and related products are entering the world's oceans each year.[1] The advent of the supertanker has given rise to the threat of local cataclysms; indeed, many have occurred (*e.g.*, *Torrey Canyon*, *Ocean Eagle*). These large spills are significant, but it is important to consider the smaller spills as well. The damage done by one careless boater who tosses overboard the contents of a coffee can full of water and oil from his boat's bilges might seem insignificant, but when his act is multiplied by a thousand or a million users of one body of water, the damage approaches catastrophy. Efforts must be continued to control the oil pollution problem and its resulting damage to commercial fisheries, recreational waterways, and the aesthetic value of an area from all sources of oil spill incidents.

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[1] Blumer, Max, "Scientific Aspects of the Oil Spill Problem," *Environmental Management: Science and Politics*, Morton and Marsha Gordon, ed., p. 324, Allyn & Bacon, Inc.,

This thesis intends to analyze the decision process of firms engaged in potentially polluting industry in an effort to isolate the effects of penalties and other pollution costs. The intent is to provide the Marine Environmental Protection (MEP) program manager with an understanding of the consequences of alternative strategies on the control of pollution in his area.

An economic model of the firm's decision process will be developed, and a simple analysis using a variety of decision strategies will be made, using the model, to determine the various results from different strategies.

The number of theorists in any field always seems to outnumber those with practical answers for the manager to use. The theoretical model in this thesis will be analyzed with respect to the existing data base to determine whether or not it has any practical application.

A final function of this thesis is to suggest other areas for potential research in the area of MEP program and systems management and to provide a critique of the existing data system in an effort to make it more responsive to the Coast Guard, as an enforcement agency, and to the researcher of oil pollution questions. These recommendations are in the form of NOTES, which are inserted as appendices at the end of this paper.

Certain assumptions are necessary to this study. There are also limitations to the theoretical model which has been developed, but these do not demean the research, rather they

make it more useful to the manager, if he recognizes the instances when he can use this information. This thesis will treat the firm as a strict economic entity and attempt to model its decision process. The firm is considered a rational actor in a free economy which always acts to maximize its expected profits. It is recognized that other factors enter into the firm's decision process. The social consciousness of the management, other objectives beyond profit-making, and external pressures on the firm will alter the pure profit-making motive and, hence, the predicted reactions. But it is important, in an initial analysis, to exclude the idiosyncracies of individual firms when generalizing about how a firm will react to pollution abatement policy. It is important for the enforcement agency to understand the firm's decision process relating to oil pollution control. If an enforcing agency can visualize the firm's decision process, then it can apply more efficient and functional resources to reduce the problem.

Most of the economic analysis of pollution problems has been concerned with the control of continuous pollution. The problem of chronic oil discharge into the water has been virtually eliminated as a result of federal and local regulations and laws forbidding the introduction of oil or hazardous substances into the water. Although the recent laws are only as effective as the enforcement, the great visibility of oil on water and the new environmental

consciousness by the public has helped eliminate the problem of the chronic polluter.

It is the isolated and intermittent oil spill which now needs more attention. The literature offering solutions to this problem is sparse. The principle work that this author was able to uncover dealing specifically with the economics of oil spills was an article by Paul G. Bradley, "Marine Oil Spills -- A Problem of Environmental Management," Natural Resources Journal, June, 1974. Bradley explores the factors which enter into the costs of an oil spill and he reviews the suggested methods for controlling oil spills. Finally, he outlines some considerations for designing institutions to maintain environmental quality. It is interesting to note that his cost models vary only slightly, and not significantly, from those developed in this thesis, independent of his work.

The data used in this thesis comes from the U. S. Coast Guard's Pollution Incident Reporting System (PIRS). The years 1973 and 1974 were chosen, since the data collected in these years reflect current regulations and standards of reporting. The PIRS system was first developed for use in late 1971 to collect data relative to the nature of oil discharges into the waters of the United States. After the Federal Water Pollution Act was amended in 1972, the data base was greatly expanded to meet growing demands on the Coast Guard for information on oil pollution incidents.

Data is collected on standard forms by local Coast Guard units which receive the information from internal reports and reports from other agencies, corporations and private individuals external to the Coast Guard. The forms are coded at the District offices and sent to Coast Guard Headquarters periodically, where the data is batch processed and stored on magnetic tape. The record contains 424 characters with more than 68 data fields. Copies of the standard forms and the record format are included as Appendix A to this thesis.

At this point, it may be valuable to include an introductory chapter on the history and magnitude of the oil spill problem, but that information is well documented in many other writings. This thesis does not intend to add to that general debate. Instead, a theory for practical application in controlling oil spills will be explored and suggestions will be directed toward helping the manager of a law enforcement agency, such as the Coast Guard, form appropriate policy to control more efficiently the oil spill problem.

II. OIL POLLUTION LAWS AND REGULATIONS

The enforcement of laws related to the use of the seas has been a traditional Coast Guard role; however, in the last 185 years that role has evolved beyond the original scope of the Revenue Cutter Service. It now includes regulations of vessel safety and operating standards, enforcement of fisheries laws, oil pollution prevention and control, and many other duties that probably never occurred to Alexander Hamilton when he established the Coast Guard in 1790.

One of the newest and continually changing roles of the Coast Guard is in the area of oil and hazardous substance regulation and control. A long list of pieces of legislation have been credited with moving the Coast Guard into the marine environmental protection field; but, in a sense, the interests of the service were already there. The inspection of the merchant vessel fleet, responsibility for boating safety, and Captain of the Port duties have made the Coast Guard historically concerned and the logical agency to deal with the problem of oil pollution on the waters of the United States.

The National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 1510) contains a listing of the legal authority which is the background for statutes, regulations, and administrative orders related to oil pollution control. This list is Appendix VII of the Plan.

The primary piece of legislation that accelerated the nation's efforts toward oil pollution control, however, is the Federal Water Pollution Control Act, as amended, of 1972. It provided the basis, in law, for much of the Coast Guard activity related to the implementation and enforcement of the Marine Environmental Protection Program.

The FWPCA established the requirements and prohibitions relating to the action of industry, shippers and private individuals with respect to oil pollution. The major sections of the FWPCA which concern the Coast Guard are those which require any discharge of oil or hazardous substance to be reported to the Coast Guard and which state the responsibilities of the spiller with respect to removal of the discharged substance. In addition, the Act sets the level of civil and criminal penalties which may be assessed on violators of the Act. It also states the national policy with respect to restoration and maintenance of the integrity of the nation's waterways as follows:

> PL-92-500 Sec. 101(a)(1) "it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985;
> ....(3) it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited;
> ....(6) it is the national policy that a major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone and the oceans."

To that end the Act designates the Administrator of the Environmental Protection Agency as the Administrator of the Act and establishes authorities and responsibilities of other

agencies with respect to the law. This thesis is primarily concerned with the penalties and costs associated with oil pollution. Major requirements and penalties for failure to comply with the laws and regulations regarding oil pollution follow:

FEDERAL WATER POLLUTION CONTROL ACT of 1972

1. The law forbids the discharge of oil or hazardous substances into or upon the navigable waters of the United States, adjoining shorelines, or the contiguous zone in harmful quantities. The definition of what determines a harmful quantity is taken up in regulations established by the EPA.

2. Any owner or operator from which oil or hazardous substances is discharged is liable for actual costs of removal of the discharge within certain limits.

3. The law requires vessels to establish financial responsibility for spill removal costs in the form of insurance, surety bonds, or other evidence of responsibility. This regulation applies to all vessels over 300 gross tons except barges which do not carry oil or hazardous substances as cargo and are not self-propelled. The amount of evidence required is one hundred dollars per gross ton or 14 million dollars, whichever is less.

4. Specific penalties for violation of the Act and its provisions are as follows:

a. A civil penalty may be assessed for a discharge which is determined to be unremovable. This provision was not in effect for an appreciable time during the period under study; but it is interesting to point it out, since future penalties may fall into this category.

(1) The penalty is to be from five hundred dollars ($500) to five thousand dollars ($5000) based on the toxicity, degradability, and dispersal characteristics of the pollutant.

(2) Or a civil penalty based on a standard unit of measure equal to from one hundred dollars ($100) to one thousand dollars ($1000) per unit may be assessed. This penalty is not to exceed five million dollars ($5,000,000).

b. Failure to notify the Coast Guard of an oil spill incident makes the violator liable for a criminal fine of up to ten thousand dollars ($10,000) or one year imprisonment or both.

c. Failure to post proper bonds of financial responsibility can result in civil penalties of up to ten thousand dollars ($10,000).

d. Removal limitations have been set as follows:

(1) one hundred dollars ($100) per gross ton or fourteen million dollars ($14,000,000) whichever is less (for vessels) and

(2) eight million dollars ($8,000,000) for shore facilities.

(3) These limits can be extended if negligence or intent can be established.

e. Civil penalties for violation of regulations are issued by appropriate agencies with respect to:

(1) methods and procedure for removal

(2) criteria for development of local and regional contingency plans

(3) procedures, methods, equipment and other requirements to prevent discharges and to contain those that do occur

(4) governing vessel inspections to reduce the likelihood of a discharge

(5) each violation is considered a separate offense, each of which is subject to a five thousand dollar ($5000) limitation.

As a result of this law and other provisions, regulations have been drawn up by the appropriate agencies to provide specific enforcement definitions and requirements. A review of present regulations affecting industry and private individuals is appropriate, since it sets the basis for the analysis of the economic decision model to be developed. The limitations and levels of penalties and cleanup costs will figure into the decision model and determine upper limits on the impact of enforcement agency penalty levels.

The primary source of data on regulations is the Code of Federal Regulations and the Federal Register. Appropriate sections of the Code are:

40 CFR 1510: National Oil and Hazardous Substances Pollution Contingency Plan (Federal Register, vol. 40, No. 28, February 10, 1975)

40 CFR 109: Criteria for State, Local and Regional Oil Removal Contingency Plans (EPA)

40 CFR 110: Discharge of Oil (EPA)

40 CFR 112: Oil Pollution Prevention (EPA)

10 CFR 113: Liability Limits for Small Onshore Storage Facilities (EPA)

33 CFR Subchapter O: Pollution (USCG)

Key elements and definitions relating to enforcement of laws and regulations and assessment of penalties for violations of the regulations follow in the discussion of the Council of Environmental Quality, the Environmental Protection Agency and the U.S. Coast Guard.

A. COUNCIL ON ENVIRONMENTAL QUALITY:

This organization sets up the National Oil and Hazardous Substances Contingency Plan and defines responsibilities and terms within the scope of the Plan. Specific definitions of interest are:

1. Minor discharge: less than one thousand (1,000) gallons on inland waters or less than ten thousand (10,000) gallons to the coastal waters (waters subject to tidal variations).

2. Medium (Moderate) discharge: one thousand to ten thousand (1,000 - 10,000) gallons in inland waters and ten to one hundred thousand (100,000) gallons to the coastal waters.

3. Major discharge: more than ten thousand (10,000) gallons inland and one hundred thousand (100,000) gallons to coastal waters OR a discharge which poses a "substantial threat to the public health or welfare."

4. Removal: cleanup or removal of oil or hazardous substances from water or shoreline or other actions taken to minimize damage.

Responsibilities for enforcement are divided between the agencies involved. The EPA has responsibility for providing the On-Scene-Commander for spills occurring in inland waters, and the Coast Guard is responsible for the Coastal waters, Great Lakes, ports and harbors.

The rest of the plan concerns directions and procedures for mobilization of regional and national actions to clean up spills of hazardous substances.

B. ENVIRONMENTAL PROTECTION AGENCY:

The EPA has the broadest responsibilities with respect to pollution control. In regard to oil pollution, the agency:

1. Establishes the requirements and guidelines for preparation of state, local and regional Oil Removal Contingency Plans, and the coordination of those plans with the National Plan.

2. Prohibits the discharge of harmful quantities of oil into the navigable waters of the U.S. that:

a. violate water quality standards

b. present a film, sheen discoloration or sludge-emulsion

3. Discharges into the contiguous zone are considered harmful under the same rules, except where altered by International treaty or convention

4. Prohibits the use of dispersants or emulsifiers to circumvent the provisions of the FWPCA

5. Requires the discharger to notify the U.S. Coast Guard

6. Requires owners and operators of onshore and off-shore facilities to prepare a Spill Prevention Control and Countermeasure Plan (SPCC) that:

a. is effective in satisfying the requirements within the regulations

b. is certified by a Registered Professional Engineer

c. meets the approval of the regional administrator of the EPA.

7. Calls for a civil penalty of five thousand dollars ($5000) per day for failure to provide a SPCC by a certain date. This date is a function of when the firm begins operations.

8. Sets guidelines for Spill Prevention Control and Countermeasure Plans.

C. U.S. COAST GUARD:

The role of the Coast Guard is restricted to regulation of oil pollution incidents that occur on the navigable waters and adjacent shorelines of the United States. Coast Guard regulations:

1. Establish prohibited zones for discharges
   a. within fifty (50) miles of the coast
   b. other designated areas
2. Require the keeping of an Oil Record Book.
3. Delegate authority to the District Commander to assess civil penalties under the FWPCA.
4. Require the notification of the Coast Guard by rapid communications.
5. Establish equipment and operating standards and inspection requirements for facilities which may discharge hazardous substances into the water.
6. Authorize the Captain of the Port to suspend operations of dangerous or potentially dangerous firms.
7. Establish personnel qualifications, requirements for operating manuals, and vessel design standards relating to oil and hazardous substance storage and transfer.
8. Administer the Pollution Cleanup Revolving Fund.

This discussion is designed to highlight the regulations and penalties for violation of the regulations pertaining to pollution of the oceans and waters by oil. These regulations and penalties serve as the basis for analysis in later chapters of this thesis.

III. ECONOMIC MODEL DEVELOPMENT

In order for an enforcement agency to improve its effectiveness, it must have an understanding of the behavior of the group toward which its efforts are directed; and it must understand how its activities are perceived and internalized into the decision process of the target organizations. It is the purpose of this section to present a simple model of the behavior of a firm in this economy as it relates to the oil pollution problem. The variables that will be isolated are those which deal with the costs that the firm must consider relative to pollution prevention and the parameters controllable by the enforcement agency.

It will be assumed that the firm is a purely economic actor with the objective of maximizing expected profit. This assumption might be considered a lower bound on the costs that a firm is willing to accept to avoid the expected costs associated with spillage of oil. In actual practice, the firm is likely to place some value on other strategies, such as community standing or political concerns, and might be expected to accept higher costs to achieve those objectives.

Initial development of the model will assume that the firm expects some spillage to occur and can internally set the expected spill volume and frequency (S). The efforts that the firm takes to set S will be called r.

$$S = f(r)$$

The first step in the analysis is to look at the production function of the firm as it relates to the input of oil or some other hazardous substance. The firm produces an output (z) using inputs of oil (x). The simple production function for the firm can be stated as:

$$z = g(x)$$

As oil inputs increase, the level of output should increase, therefore the first order conditions for the production function follow:

$$\frac{\partial z}{\partial x} > 0$$

The input variable x excludes the amount of oil that is wasted through spillage and can be given as the difference:

$$x = x_1 - S$$

where x_1 is the total amount of oil that must be purchased for production, and S is the spillage that occurs. Relating S to r again, it would be expected that increased efforts to prevent pollution should decrease S.

$$S = f(r)$$

and

$$\frac{dS}{dr} < 0$$

It can be assumed that f(x) is not a linear function, since the firm will first employ those efforts on pollution control with the greatest marginal return before turning to efforts with greater marginal cost. This relationship is shown graphically in fig. (1).

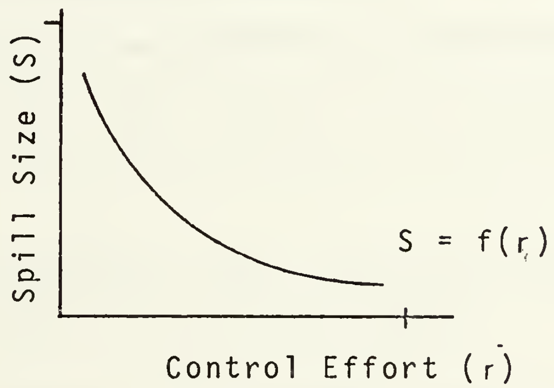


Figure 1.

The production function becomes:

$$z = g(x_1 - S)$$

If the output of the process sells for a unit price P_1, that the firm can assess with certainty, and the costs associated with production can be thought of as those related to product (x) and pollution prevention efforts (r), it is possible to construct the profit function for the firm. An additional cost enters the function, however, as a result of the laws and regulations concerning oil pollution. If a discharge occurs, there is some probability that the firm

will be assessed a penalty and/or be required to remove the pollutant. The cost of pollution relative to those costs is called P_2 and must enter into the profit function.

The costs associated with the firm's profit function in this instance are:

1. Input costs = kx_1 where k is the market price of the input

2. Pollution prevention efforts = r

3. Penalty costs associated with spillage

$$P_2 = q[C \times p(C) + R \times p(R)]$$

where:

q = probability that the spill will be detected

C = level of the civil penalty

P(C) = probability a penalty will be imposed

P(R) = probability that removal efforts will be required

The profit function can be written as:

$$\begin{aligned} \text{Profit } (\pi) &= P_1 z - kx_1 - r - P_2 S \\ &= P_1 z - kx_1 - r - q[C \times p(C) + R \times p(R)] \cdot S \end{aligned}$$

This profit can not be expressed as a certain outcome; therefore, it is necessary to analyze the probabilistic variables to determine the firm's expected profit. The firm can assess with certainty the value of P_1 and the market price for the input (k). They will also decide on the optimal

level of r to satisfy the optimization decision. The major uncertainty relates to the cost of penalties for polluting. The expression for expected profit can be expressed as:

$$E(\pi) = E(P_1 z) - kx_1 - r - E(P_2 S)$$

For the continuous optimization problem, the firm will use the level of pollution expenditures and the amount of input they will purchase as the decision variables. In order to evaluate this condition, the partial derivative of the expected profit function will be taken with respect to the decision variables and the result set equal to zero. The results of this exercise will be the optimal economic decision for the firm based on the model assumptions.

Beginning with the derivative of expected profit with respect to input, the results are:

$$\frac{\partial E(\pi)}{\partial x_1} = E\frac{(P_1 \partial z)}{\partial x_1} - k$$

Setting this equation equal to zero and separating the costs and revenues it follows that:

$$E\frac{(P_1 \partial z)}{\partial x_1} = k$$

The firm's decision, then, with respect to input is that they will continue to purchase oil as long as the revenue received as a result of the last unit of oil purchased is equal to its market price. This decision results from the following analysis.

It is to be expected that additional inputs of product should have the effect of increasing output. The sign of marginal revenue with respect to input is positive. But, using classical economic theory, one expects diminishing returns for additional units of input. Therefore:

$$P_1 \frac{\partial z}{\partial x_1} \geq 0$$

and

$$P_1 \frac{\partial^2 z}{\partial x_1{}^2} \leq 0$$

The graphical representation of this function follows in fig. (2).

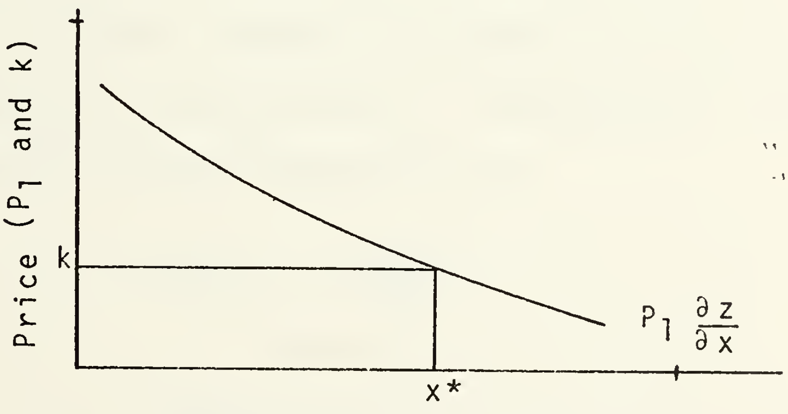


Figure 2.

The marginal revenue function will be downward sloping to the right with increasing x_1. The optimal operating point is then, where

$$k = E(P_1 \frac{dz}{dx_1})$$

The second decision variable is r. The partial derivative of $E(\pi)$ with respect to r is:

$$\frac{\partial E(\pi)}{\partial r} = E(P_1 \frac{\partial z}{\partial r}) - \frac{\partial E(P_2 S)}{\partial r} - 1$$

In the conventional form with revenues and costs separated

$$E(P_1 \frac{\partial z}{\partial r}) = 1 + \frac{\partial E(P_2 S)}{\partial r}$$

The decision criteria, however, is based on the optimal level of pollution control effort r. Rewritten in that form the equation for optimal allocation is:

$$1 = E(P_1 \frac{\partial z}{\partial r}) - \frac{\partial E(P_2 S)}{\partial r}$$

assuming

$$\frac{\partial z}{\partial r} > 0$$

$$\frac{\partial E(P_2 S)}{\partial r} < 0$$

The firm's decision criteria is, then, to continue to employ additional efforts on pollution control until the resulting increase in marginal revenue plus the decrease in

expected penalties is less than or equal to the cost of one more unit of effort on pollution control. Figure (3) shows the graph of the optimal solution.

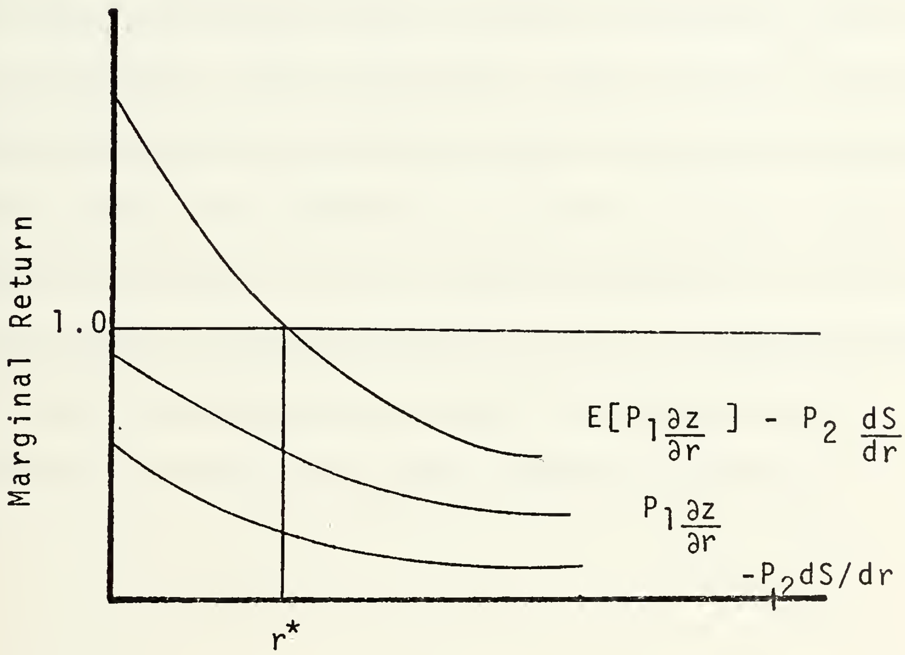


Figure 3.

The previous discussion is theoretical in nature and only accounts for the firm's expected profit motivation. The firm, in a more realistic sense, will have additional inputs into its pollution control strategy other than profit maximization. These inputs may be manifestations of the personal values of the controlling managers and operating personnel, perceived

obligations of the firm to society or other factors which will serve to alter their pollution strategy around the profit maximization objective. It is still useful to understand the profit motivation in order to have a baseline for analysis.

The levels of x and r are internal decisions that must be made by the firm. The enforcement agency which understands how these levels are set will be able to assess the effectiveness of their own efforts to achieve their objective. The optimal strategy for the enforcing agency revolves around the firm's perceived level of P_2. This external variable must be examined in order to discover the effectiveness of the enforcement agency's efforts.

IV. DATA ANALYSIS

The development of the economic decision model in the last chapter has served to isolate the critical enforcement variables that the Coast Guard has at its disposal for the assessment of civil penalties on firms which discharge oil into the nation's waters. The next step in assessing the practicality of this model is to attempt to quantify as many of the variables as possible and determine the value of the model from the known parameters. This will enable the manager or evaluator of a penalty assessment program to determine the effectiveness of the fine structure and expected cleanup costs on the behavior of the firm.

A. METHODOLOGY

Data was taken from the Pollution Incident Reporting System (PIRS) for the years 1973 and 1974. The choice of that time period was made because the data base was expanded in late 1973 and the changes were incorporated into all incidents from January 1, 1973 to the present. The expanded system contains much more data for analysis and exists in standard format.

Before reporting the results of the data analysis, it is necessary to explain some characteristics of the data and the assumptions which resulted from those characteristics. The system contained over twenty-five thousand (25,000) records for the two-year period. There are over one hundred possible

data fields on each record. Unfortunately, the data contained a high rate of unknown or missing data, which in some instances ran as high as fifty per cent of the total for a given field. It was necessary to assume that the missing data had the same characteristics as the reported data. This may be a serious limitation to the analysis, since there are intuitive instances where that assumption might be challenged.

It appears, for instance, that information on costs is more likely to be reported on larger spills than on smaller ones, since major spills are often followed closely by the Coast Guard and documented in special reports. Data would tend to be more complete for major spills and the data would be biased toward the larger spill categories. This may be acceptable, however, since the larger spills generally are of greater concern than the smaller ones.

Much of the data was subject to subjective determination. It was impossible to separate, even within a data field, which of the information was factually determined and which was estimated. It was assumed, therefore, that all information on the data tapes was accurate. There is no need to speculate on the consequences of that assumption being false. Appendix C contains a further discussion of the data base and the problems associated with using it during this research. The assumptions about the data were necessary to make this analysis possible. Refinement of the data base would serve to improve the results of the preliminary analysis. It was

not the intention of this study to resolve the data base problems. Such efforts would require a considerably different form of analysis.

For the purposes of making the presentation concise, most of the data will be reported in aggregate form. This tends to minimize the idiosyncracies of individual firms and districts. Analysis was conducted by dividing the spill incidents into three categories by spill size. The breakdown was performed by quantity. For purposes of this study, a minor spill was any spill under 1,000 gallons. A moderate or medium spill was from 1,000 to 10,000 gallons, and a major spill was any spillage over 10,000 gallons. This breakdown conforms substantially with the categories defined in the oil spill regulations. The differences that exist can be seen by examining the definitions in Chapter II of this thesis. The differences were not apparent from the data, and they were not considered significant, since the great majority of reported spills occur within the territorial waters.

It was assumed that any spillage of oil would be discovered and reported to the Coast Guard. This assumption appears sound, since oil spilled on water is highly visible and is unlikely to escape detection, particularly in heavily traveled waterways (i.e., $q \simeq 1.0$).

Expected values for the variables of civil penalty and cost of cleanup were determined for each of the spill categories and for the total spill range for each of the two years investigated. The analysis of costs and penalties as

continuous functions was attempted, but the results were inconclusive. The limited results will be reported at the end of this chapter.

Individual firms will assess their own pollution potential and adjust their strategy to their own particular situation. The oil pollution record of one large firm will be examined and compared with the results for the industry. The firm examined is used only as an example and is not necessarily typical of any individual firm's record.

The costs associated with spills of a given category were aggregated to allow a discrete analysis of the decision process regarding external controls. During the initial formulation of the model, P_2 was assumed to be a per unit cost of polluting. During this phase of the analysis, costs are represented as expected costs within a given size category. The value that P_2 takes on depends on the decision criterion being evaluated. For purposes of this discussion, P_2 may be considered to be the sum of the penalty and removal costs that a firm will incur for a particular size category i.

P_{21} = expected costs for the case when no spillage occurs

P_{22} = expected costs if a minor spill occurs

P_{23} = expected costs if a moderate spill occurs

P_{24} = expected costs if a major spill occurs

The probabilities of any spill of size S_i occurring in a given time period are given by:

f_1 = probability that no spill occurs

f_2 = probability that a minor spill occurs

f_3 = probability that a moderate spill occurs

f_4 = probability that a major spill occurs

To simplify analysis, it has been assumed that

$$f_1 = 0$$

and

$$f_2 + f_3 + f_4 = 1.0$$

This assumption is reasonable if the aggregate data is used or if the time horizon for a particular firm is sufficiently large. Since approximately ten thousand spills occur every year, it is difficult to imagine a year going by without any spillage occurring. To be more correct, some small non-zero value should be attached to f_1 to indicate that efforts to control pollution do have some positive effect on reducing the number of spills which occur.

In fact, for a firm which can successfully control spillage, the value of f_1 for that firm approaches 1.0. In general, it can be stated that:

$$\frac{df_i}{dr} \leq 0 \qquad \text{for } i = 2,3,4$$

and

$$\frac{df_i}{dr} \geq 0 \qquad \text{for } i = 1$$

For the individual firm it might be more appropriate to use a distribution which results in f_1 being assigned a finite value based on the expected number of discharges for that particupar firm. Intuitively, it appears that a Poisson distribution might be appropriate.

For the case under consideration, the optimization conditions may be stated as:

$$1 = E(P_1 \frac{\partial z}{\partial r}) - \Sigma P_2 \frac{df_i}{dr}$$

If each of the expected values can be determined, it is possible to determine the expected costs associated with oil pollution. The additional gain to the firm will come from the product which is retained and placed into the production process to increase output. The firm sets its level of pollution control such that the expected number of spills and the costs associated with those spills added to the increased production resulting from the additional efforts equals the cost of the last unit of control effort.

It is useful to look at the optimization conditions as they relate to this simple case. As in the previous, more general model, the values of the variables can be graphed to determine the optimal conditions. The discrete analysis depicts each category of spill as a separate function as shown in fig. (4). Since:

$$\frac{dfi}{dr} < 0 \quad \text{for } i = 2,3,4$$

and

$$\frac{df_i}{dr} > 0 \quad \text{for } i = 1$$

the necessary condition for a unique solution to the problem is that all functions are downward sloping to the right.

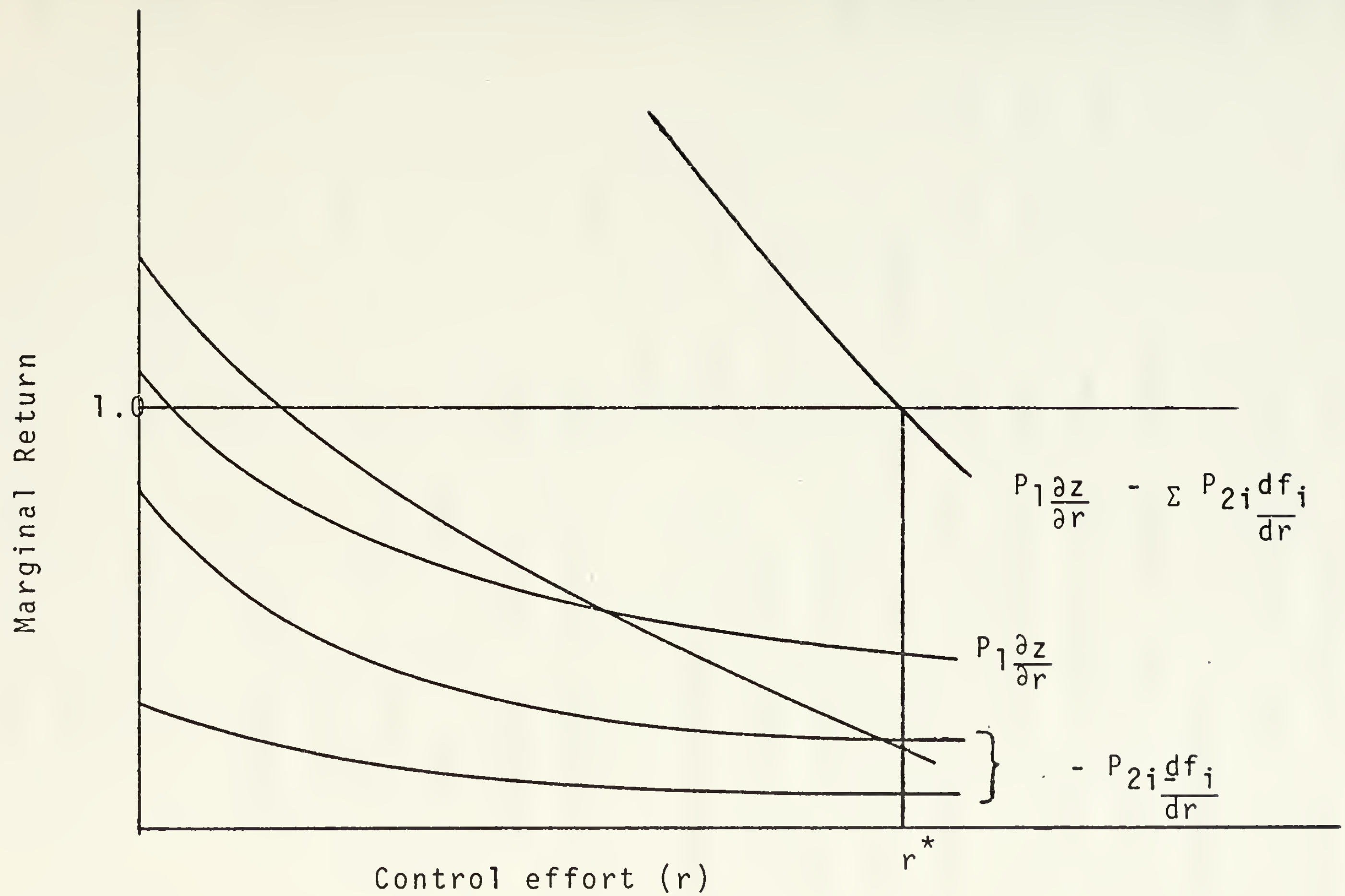

Marginal Return
1.0
$P_1\frac{\partial z}{\partial r} - \Sigma P_{2i}\frac{df_i}{dr}$
$P_1\frac{\partial z}{\partial r}$
$- P_{2i}\frac{df_i}{dr}$
r^*
Control effort (r)

Figure 4.

The impact of this representation is to show that the firm will emply the efforts which achieve the greatest return for each dollar spent on prevention. The optimal course of action can be determined once their is an understanding of the costs associated with the prevention of spills within a given size category. Quantification of those costs is an important question for further analysis.

The firm may employ other strategies based on its view of the distribution of penalty costs and its degree of concern over the impact of those costs. For instance, the expected profit model does not account for the variance of costs about the expected value. As the variance increases the firm is likely to examine other decision criteria in addition to expected value.

If a firm wishes to avoid the worst possible situation, it will be motivated to employ a minimax strategy. In place of the expected value of the (P_{2i}) penalty costs, the firm will assess the maximum value for P_{2i} and analyze the appropriate strategy using that value. Table X, in the next section, shows the results of the minimax strategy on the firm's assessment of oil spill costs.

Other decision criteria to be examined are:

1. Maximum likelihood -- The firm assumes that the most probable event will occur (the mode), and uses that value for P_{2i}.

2. Median -- The firm may use the median rather than the mean to determine expected costs. This would be a greater

likelihood if a few large values tended to skew the results of the cost analysis.

Expected utility maximization is a variable on the expected profit motivation. It will not be explicitly examined in this study, but is worthy of mention as a possible alternative measure which incorporates a degree of risk into the optimization function. Using expected utility as its criterion, a firm would need to assess the level of utility associated with various costs of pollution incidents and set the optimum level of operations at the point where the marginal utility per dollar spent is equal for pollution control, penalties avoided and marginal revenue. The advantage of marginal utility analysis is that it incorporates a measure of the firm's assessment of the value of various rewards and penalties for oil pollution. After a cursory examination of the possible effects of quantifying a firm's expected utility maximization on the model developed here, it was decided not to include this variable since the results would not significantly alter the trends illustrated by the model.

After the presentation of data illustrated in the next section, certain decision criteria will be evaluated by inserting the values achieved from the analysis into the optimization formula as the value for expected costs. The firm's level of pollution control using the various criteria will be analyzed for their applicability to the existing

pollution environment and to future decisions on the part of the enforcement agencies and policy makers.

B. DATA PRESENTATION

Aggregated data for 1973 and 1974 is presented in the form of tables and figures depicting the distribution of the data. Tables I and II contain the principle breakdown of costs for the two-year period. The expected costs shown in those tables do not always show the true distribution of the data; therefore, figures 5 through 8 are included to show, graphically, the distribution of penalty and cleanup costs. Table III summarizes the median, mode, and maximum values from the figures.

The cost data for a large corporation was extracted from the data to illustrate an individual firm's record and determine whether or not its record was distributed similarly to the industry's. These figures are summarized in Table IV.

Finally, a breakdown of the data by District is given in Table V. The data is not specifically analyzed in the study, but variations between districts is evident. Further analysis of the differences would help to define more clearly the strategy of firms within a particular area.

Table I.

SUMMARY OF OIL SPILL COSTS

1973

Category	Number of Spills	Avg. Spill Size	Avg. Penalty [1] (C)	% of Spills Pen. p(c)	Expected Penalty	Avg. Removal Costs (R)	% of Spills Removed p(R)	Expected Removal Costs	Total Expected Cost of Spill P_i
Minor	9042	61	$1036	29.4	$ 300	$ 10750	4.1	$ 440	$ 740
Moderate	522	3354	1909	60.	$1100	16700	10.	1670	2770
Major	129	162000	3000	56.	$1700	216000	12.4	26800	28500
All Spills	9693	2390	1168	31.	$ 370	19000	4.5	$ 850	$ 1220

1. Average penalty for all incidents for which penalties were reported.

Source of Data: PIRS 1973 computer file

Figure 5.

DISTRIBUTION OF CIVIL PENALTIES -- 1973

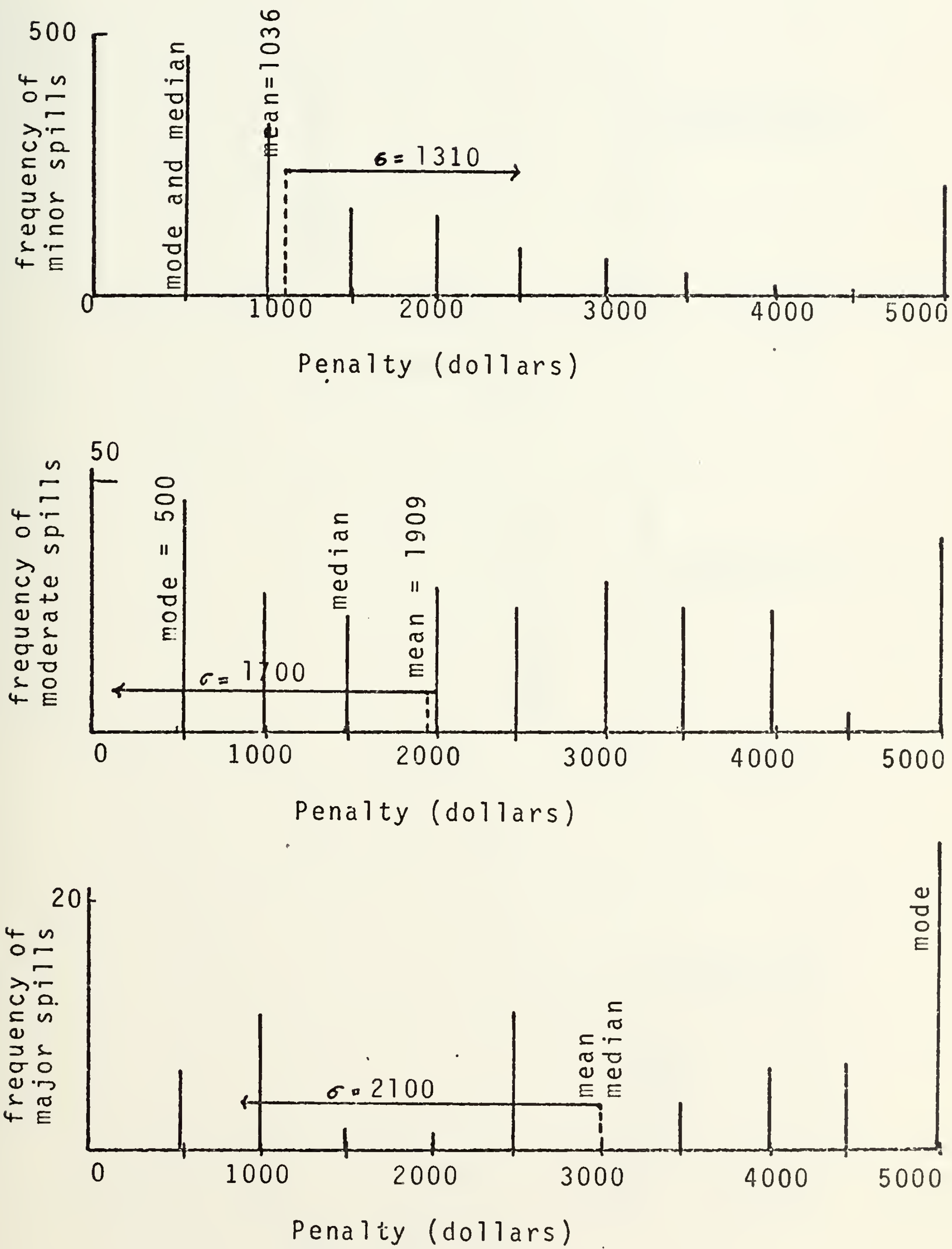


Figure 6.

DISTRIBUTION OF REMOVAL COSTS - 1973

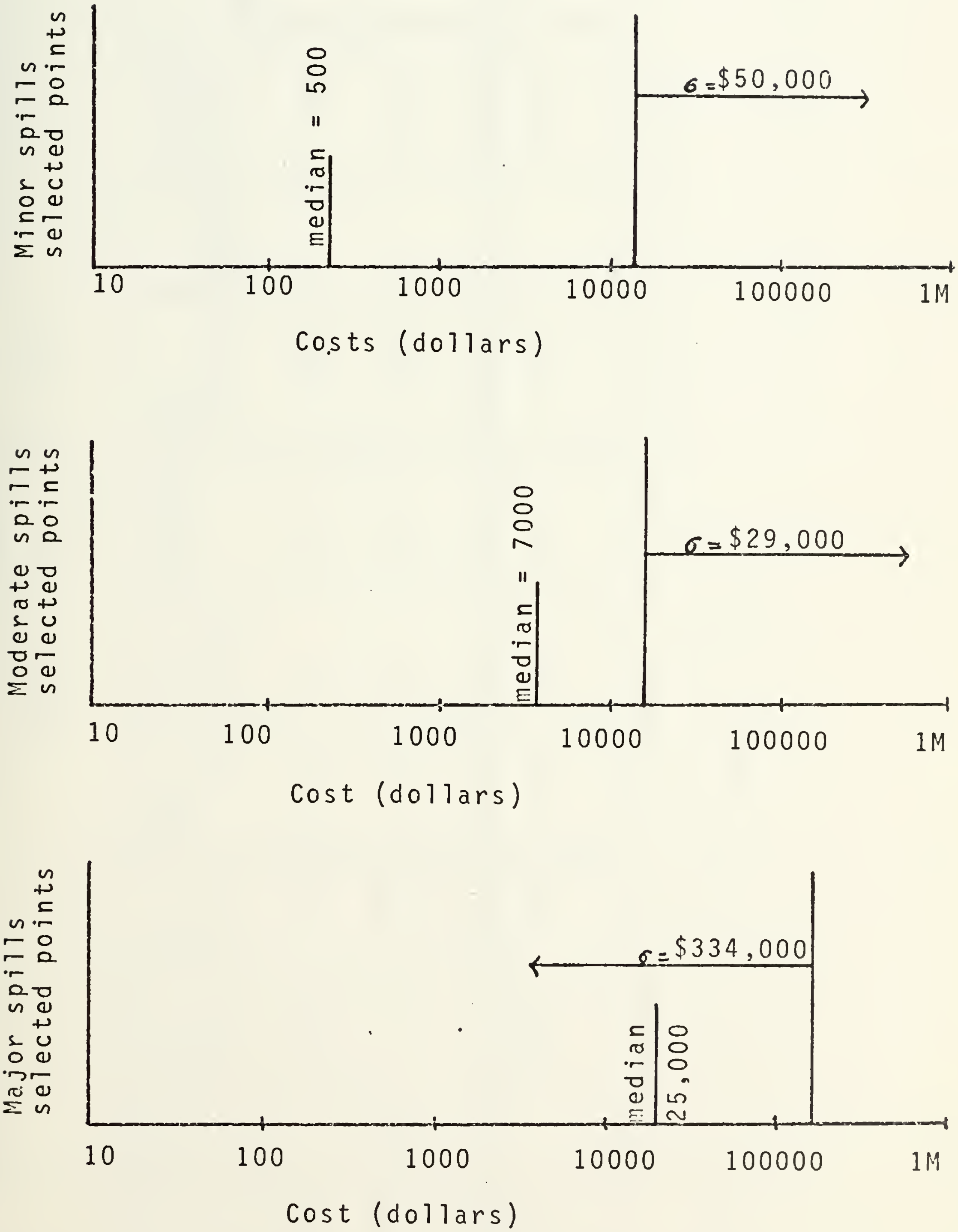


Table II.

SUMMARY OF OIL SPILL COSTS

1974

Category	Number of Spills	Avg. Spill Size	Avg. Penalty [1] (C)	% of Spills Pen. p(C)	Expected Penalty	Avg. Removal Costs (R)	% of Spills Removed p(R)	Expected Removal Costs	P_{2i} Total Expected Cost of Spill
Minor	9454	65	$ 765	24.	$ 200	$ 7063	12.	$ 850	$ 1050
Moderate	723	3300	1664	30.	500	59600	16.	9500	10000
Major	191	73000	2710	27.	750	250000	14.	35000	35750
All Spills	10368	1700	882	24.	215	17000	12.	2000	2215

1. Average penalty for all incidents for which penalties were reported.

Source of Data: PIRS 1974 computer file

Figure 7.

DISTRIBUTION OF CIVIL PENALTIES - 1974

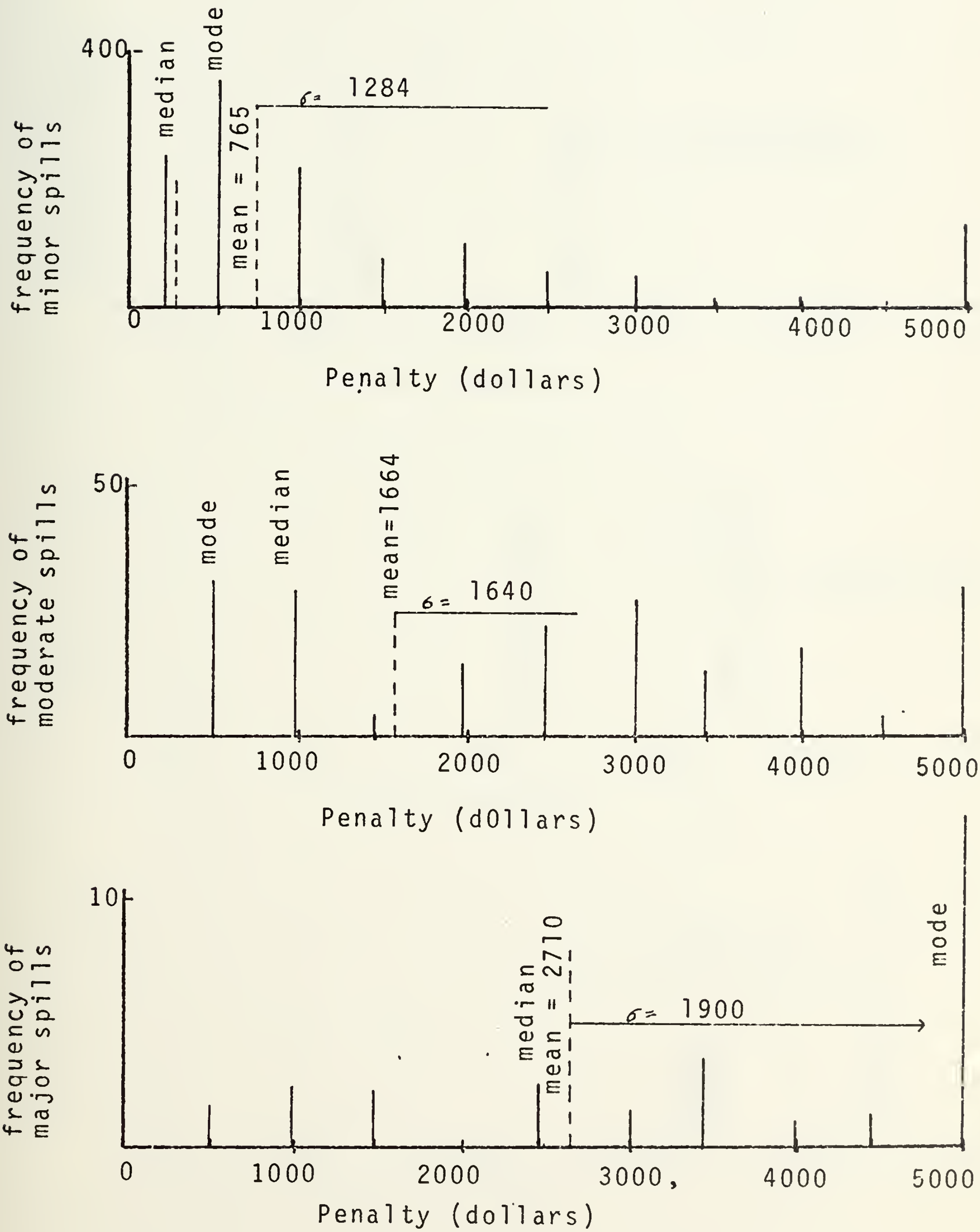
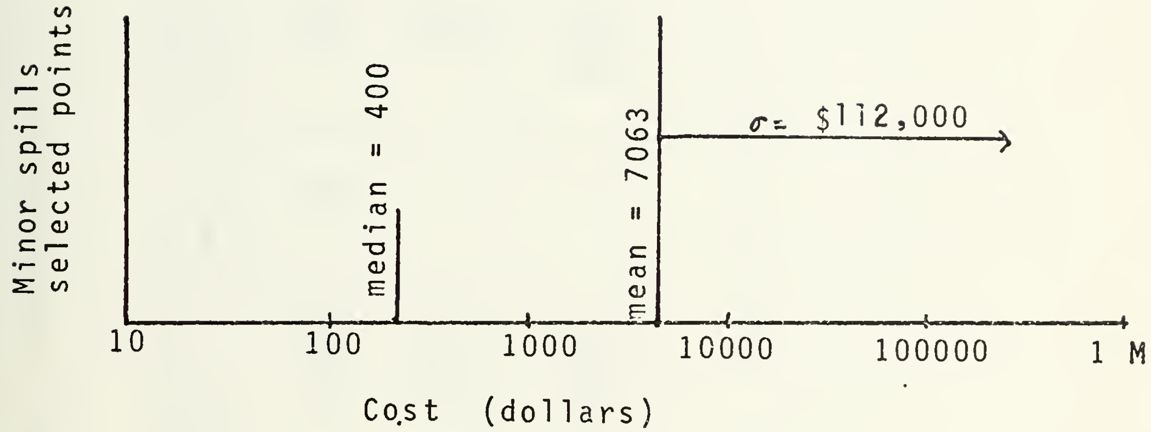
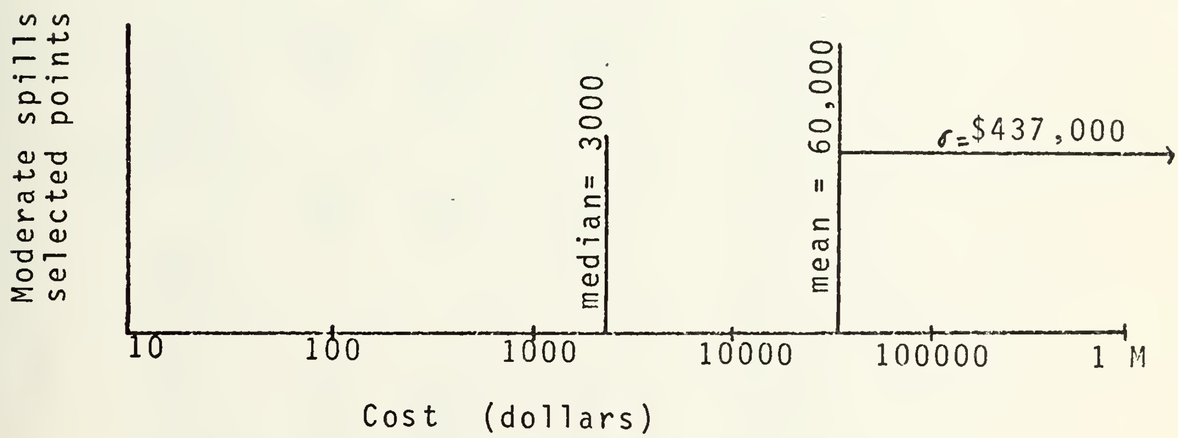


Figure 8.

DISTRIBUTION OF REMOVAL COSTS - 1974





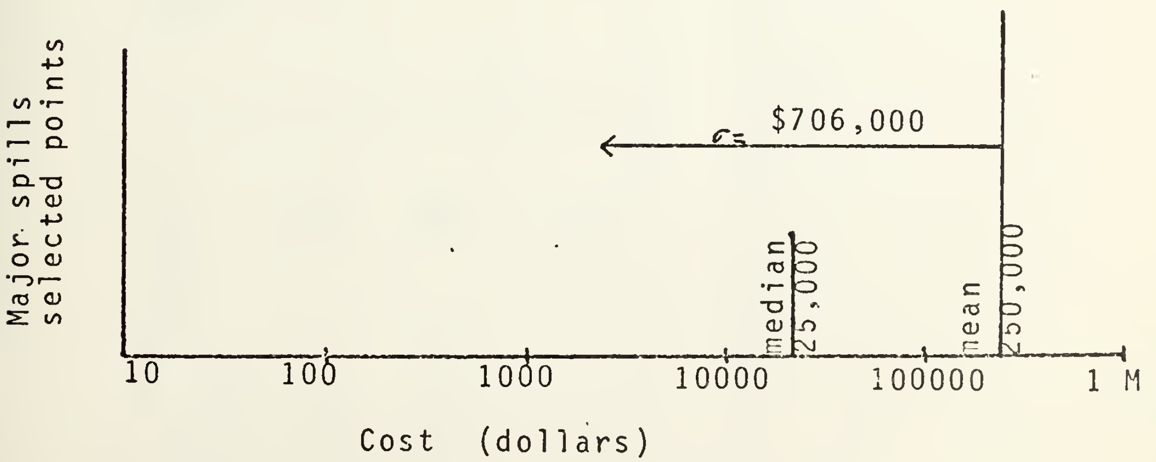


Table III.

PARAMETERS OF OIL SPILL COST DISTRIBUTIONS

1973 - 1974

Category		Maximum Civil Penalty	Mode Civil Penalty	Median Civil Penalty	Maximum Removal Costs	Mode Removal Costs	Median Removal Costs
minor	1973	$ 5000	$ 500	$ 500	$ 500000	$ 500	$ 500
	1974	20000	500	350	3000000	100	400
moderate	1973	8500	500	1500	150000	@	7000
	1974	5000	500	1000	4400000	@	3000
major	1973	11000	5000	3000	1000000	@	25000
	1974	5000	5000	2500	3500000	@	25000

@ Removal costs in these categories did not recur. The mode does not provide any useful information for analysis.

Table IV.

SUMMARY OF OIL SPILL COSTS

One Firm's Record 1973-1974

Category and Year	Number of Spills	Avg. Spill Size	Avg. Penalty 1	% of Spills Pen.	Expected Penalty	Avg. Removal Costs	%of Spills Removed	Expected Removal Costs	Total Expected Cost of Spill
minor									
1973	132	79	$ 750	16	$ 120	$ 75	1.	$ 1	$ 121
1974	71	94	730	16	110	30	3.	1	111
moderate									
1973	2	1680	0	0	0	0	0	0	0
1974	5	3522	0	0	0	0	0	0	0
major									
1973	1	525000	200	100.	200	970000	100	970000	970200
1974	0	0	0	0	0	0	0	0	0
all sizes									
1973	135	4000	723	16	120	300000	1.	3000	3120
1974	76	320	629	15	90	30	3.	1	91

1. Average penalty for all incidents for which penalties were reported.

NOTE: This data is presented as it appears in the PIRS files and does not imply legal proof of the source of the discharge.

Table V.

PENALTY ASSESSMENT IN RELATION TO SIZE OF SPILL [1]

Civil Penalties by District - 1973

Category	District 01	02	03	05	07	08	09	11	12	13	14	17	all dist
Minor	440	324	860	900	1375	975	1260	700	360	430	5000	154	1036
Moderate	1560	615	3000	1650	2223	1760	3000	2000	1333	1960	5000	380	1909
Major	1350	834	4365	0	3666	3321	5000	2000	0	3500	0	5000	3000

1. Costs are averages over the number of spills incurring penalties within each District.

C. APPLICATION OF THE MODEL TO DATA

Four categories of oil spill problems will be analyzed within the context of the decision model. The first two are special cases, which, by their existence, set the basic level of pollution control costs for the industry. The other cases use the collected data to examine the results of the model for the discrete and continuous cases.

The present level of oil spill control exists, in part, by a desire of the firm to reduce the costs of lost product and the impact of government regulations and controls on standards of operations. In the absence of penalties and controls the firm would be motivated to allocate resources to pollution control as long as the expected marginal revenue gained from the last unit of control effort was greater than the cost of that additional unit of effort.

$$1 = E\left(P_1 \frac{\partial z}{\partial r}\right) \qquad \text{i.e. } P_2 = 0$$

There is evidence to indicate that this strategy may apply to the present situation under conditions where P_2 is small relative to marginal revenue. The analysis of the discrete case will treat this question in more detail.

The introduction of government regulations on the industry added an additional factor to the decision process in the form of penalties for spillage and failure to meet the standards and requirements established by law. The impact of these regulations can be assessed by analyzing them qualitatively in the context of the decision model.

$$1 = E(P_1 \frac{\partial z}{\partial r}) - \frac{\partial E(P_2 S)}{\partial r}$$

A firm which has a continuous or chronic discharge of oily wates as a result of inefficiencies in operations or a chosen strategy to rid itself of by-products of the production process must secure a permit for the discharge. The Environmental Protection Agency is responsible for issuing permits to discharge into the waters of the U.S. It is their policy to deny permission for any discharge of harmful quantities of oil. To the extent that the policy is applied and enforced, the problem of continuous discharge is controlled. The firm will set the level of P_2 equal to the expected level of penalties for continuous discharge. The fine of $5000 per day and the additional liability for cleanup operations would seem to be a significant motivator to cease chronic pollution.

The effort that is required for the firm to reduce the penalty is the effort which causes the discharge to cease to be harmful. The consequences of the high penalties and removal costs should be enough to convince all but the most determined firms to cease continuous discharge of oily wastes. If that fails, however, the Commander of the Coast Guard District may suspend operations at that site until the situation is remedied. The firm is forced to accept the costs of controlling the discharge or face loss of revenue for an indefinite period.

The degree to which efforts to control continuous pollution are effective is determined by the enforcement and public relations effort. The visibility of oil on water and the existing level of surveillance by the Coast Guard and the public indicates that a continuous discharge will be recognized promptly and is, therefore, not a critical question at this time.

The second factor which sets the base level for pollution control activity is the existence of regulations and standards for equipment and operations. Existing regulations are summarized in the second chapter of this thesis. In the context of the decision model, a firm must comply with those regulations or face similar penalties to the chronic discharge case. The range of penalties for violation of standards, however, is much greater than for discharges. A penalty for the individual violation can be applied, or the Coast Guard District Commander or EPA Regional Administrator can use his prerogative to suspend operations of a firm that poses a potential discharge threat. The effect of maximum penalties on the firm are the same as for the continuous discharge case. The smaller penalties for individual violations of regulations may provide less incentive, and would be more subject to enforcement variations. Each penalty could be analyzed on an individual basis. It is the purpose of this discussion to point up the impart of the regulations on the

decision process which sets the firm's level of pollution control efforts.

To determine how a firm will decide to incur additional costs beyond the base of control effort described in regulation, it is necessary to analyze the expected costs associated with a pollution record. The costs within the spill size categories have been assessed using the aggregate data for 1973 and 1974. It must be assumed for this analysis that the firm will use that aggregate data in its decision process. This is, admittedly, an oversimplification of the situation, but it serves to test the model using some data from a large sample size.

Values for f_i for the two-year period can be found in Table VI. Expected costs in each category were multiplied by the f_i to determine the expected costs within that category using the equation:

$$E(Cost_i) = P_{2i}(f_i)$$

The results of various decision criteria are tabulated in tables VII through X. The expected value of product lost is also included in the tables to show the relationship of internal costs to the external assessments. The product costs are an estimate using twenty-five cents per gallon. They are intended to be used for purposes of determining order of magnitude only, and should not be considered accurate.

Table VI.

DISCRETE PROBABILITY DISTRIBUTION OF

OIL SPILLS BY CATEGORY

Category	Frequency of Occurrence	
	1973	1974
Minor Spills	.933	.914
Moderate Spills	.054	.070
Major Spills	.013	.016

Table VII.

SUMMARY OF OIL SPILL COSTS

Expected Value

Category	Expected Penalty and Removal Costs 1973	1974	Expected Product Loss *
Minor Spills	$700	$ 950	$ 15
Moderate Spills	150	700	60
Major Spills	400	600	450
All Spills	$1250	$2250	$ 525

Table VIII.

SUMMARY OF OIL SPILL COSTS

Most Likely (Mode) Value

Category	Expected Penalty and Removal Costs 1973	1974	Expected Product Loss *
Minor Spills	$900	$550	$ 15
Moderate Spills	@	@	60
Major Spills	@	@	450
All Spills	@	@	525

*Product Loss is used for order of magnitude only. It is based on a price of twenty-five cents per gallon which would vary greatly from time to time and from industry to industry.

@ The mode in these categories does not provide useful information for analysis.

Table IX.

SUMMARY OF OIL SPILL COSTS

Median Value

Category	Median Penalty and Removal Costs 1973	1974	Expected Product Loss *
Minor Spills	$900	$700	$ 15
Moderate Spills	450	300	60
Major Spills	350	500	450
All Spills	$1700	$1500	$525

Table X.

SUMMARY OF OIL SPILL COSTS

Maximum Loss

Category	Maximum Penalty and Removal Costs 1973	1974	Maximum Product Loss *
Minor Spills	$471,000	$2,754,000	$ 225
Moderate Spill	9,000	308,000	150
Major Spill	13,000	63,000	22500
All Spills	$493,000	$3,125,000	$23000

*Product Loss is used for order of magnitude only.
See Table VII and VIII for further explanation.

The results for the two-year period for all of the decision criteria except for maximum loss vary from one thousand three hundred to two thousand three hundred dollars ($1300 - $2300) over the entire range of spill sizes. This indicates that firms using these assumptions about the probabilities and expected costs of spillage would solve their optimization problem by employing that final unit of effort (r) which costs the same as the marginal revenue gained from that effort plus $1300 to $2300 worth of costs avoided.

The firm which uses the maximum loss assessment technique will be employing a pessimistic outlook on oil spill probabilities and costs. They will be willing to spend considerably more on pollution control. A firm with this strategy might be expected to employ an inhouse removal capability or contract with a cleanup firm in the form of a type of insurance policy against the expected costs of spillage.

The continuous case requires a much more detailed analysis of the probability and cost function. The probability function for oil spills has been determined by analyzing the data for 1973 and 1974. It has been determined that the logarithm of the quantity spilled for both years is exponentially distributed against frequency with a mean of approximately .866.

The function is given by:

$$f(\log\ \text{quantity}) = .9e^{-.9\log(\text{quantity})}$$

The chi square value for this function is:

$$\chi^2_{\text{observed}} = 1.465$$

$$\chi^2_{\text{tabulated}(.995)} = 148$$

However, attempts to find continuous functions for other variables were not so fruitful. There does not seem to be any simple linear relationship between civil penalties, removal costs and quantity spilled. Additional effort is needed to assess the continuous functions for other oil spill parameters.

V. CONCLUSIONS

The decision model which has been developed in this thesis considers the economic aspects of a firm's oil spill control strategy. The model demonstrates that a firm will determine its optimal level of pollution control expenditures by considering expected spill probabilities, potential savings gained by preventing loss of oil products, and the expected value of penalties for spillage. Assuming that the firm is a rational, economic actor, it will set its pollution control efforts at the level at which the added revenue plus the savings in penalty costs equal the cost of the last unit of pollution control effort.

Assumptions about the functional relationships between costs and changes in model parameters were made which should be tested in order to properly validate this model. The model is a simplified representation of the decision process employing microeconomic theory. Its assumptions are ones which hold true in general; however, there remains some question as to the exact nature of the relationships when the parameters are more interdependent than have been portrayed in this formulation.

The greatest value of the model from a practical standpoint is that it has isolated and inferred relationships between the major internal and external decision parameters of the oil pollution question. It provides some qualitative

framework for assessing the effect of proposed enforcement efforts on the pollution strategy of the firm. In addition, it can show the relative effects of variables which can be quantified.

The model may be extended beyond the oil pollution problem. In general, it is a simple microeconomic decision model which accounts for the effect of external costs on the behavior of a firm. It may be extended into other areas such as fisheries enforcement, other forms of pollution control, and government intervention and regulation.

The data used in this thesis has limitations which have been previously described. The results of the quantitative analysis, therefore, are only a first approximation of the relative importance of various variables. They do not provide specific parameters for the decision problem. More rigorous analysis of the data could produce more accurate and more useful results for practical application. The results of analysis using present data are reported below.

Civil penalties appear to have their greatest impact on the firm's strategy relative to the minor spill problem. The costs of product lost and the expected cost of cleanup are small relative to the penalties. As other costs increase, however, the size of the penalties reaches the upper bound of five thousand dollars ($5000). Other costs tend to become more significant, and the impact of the civil penalty becomes negligible. The expected value of the civil penalty

accounts for only a small fraction of the total expected cost of a major incident.

Cleanup or removal costs have a significant impact on the decision model. They account for the largest portion of the external costs that the firm must internalize. The threat of increased responsibility for cleanup and removal costs could have a significant effect on the pollution control decisions of the firm.

One of the most interesting results of this analysis indicates that the costs associated with the loss of product to the production process become increasingly important to the pollution control decision. This implies that the firm has a high internal motivation to reduce the probability of spillage occurring. In the major spill category, this internal motivation is equal to the total external patameters. In addition, this model does not account for the value of a lost tanker or other damaged equipment related to the oil spill that will be added to the firm's costs. It appears that in the major spill category, the firm's internal motivation to reduce the probability of spillage is as great as or greater than the present level of external pressure.

It appears at present that the externally levied costs have the greatest impact in the moderate and small spill categories. This tends to indicate that the strategy of the enforcement agencies has been to reduce the level of minor and moderate spills through the assessment of fines and removal costs.

The options available to the enforcement program manager are either to (1) increase the level of penalties, (2) increase the standards for removal of pollutants, or (3) increase the level of enforcement to increase the application of the costs to the firm. Cleanup costs can be increased by tougher controls on the degree of cleanup and removal required. Penalties can only be increased to the statutory limit. Increased enforcement effort will tend to increase the probability that the firm will be assessed a penalty and, therefore, increase the expected cost. Enforcement agencies have the authority to suspend the operations of firms which present a threat of spillage. The application of that authority to chronic violators on a consistent basis might provide added incentive to firms to control their pollution problem. Since poor operations and faulty equipment are the major causes of oil spill incidents, such a threat might provide the incentive needed to maintain equipment and train people properly.

The most significant conclusion of this application of the model is that the firm's internal costs seem to have the largest influence on its pollution control strategy. Present levels of civil penalties and cleanup cost applications do not seem to affect the strategy of the firm beyond the minor and moderate size spill problem.

A number of other interesting questions remain. Appendices B and C contain some thoughts about the data base and the determination of the cost of oil spill incidents. In

addition, it seems plausible that a simulation model could be developed for analyzing the impact of proposed enforcement strategies.

Policy questions offer another exciting area for study. What will be the impact of the addition of an import tax on oil to be used to finance the Pollution Cleanup Revolving Fund? How will it affect the decision strategy of the firm? What effect would changes in the civil penalty structure have on the decision process? Extremely high penalties are being imposed on foreign fishing vessels who violate American fisheries laws and claims of jurisdiction. Would the assessment of such high penalties be politically acceptable with U.S. firms as the targets? The present inference is that the fisheries problem is more important than the oil pollution problem?!

Much more can be done to analyze decisions and costs related to the oil spill problem. The results point to interesting and, often, non-intuitive relationships between decision parameters. The more accurate the understanding of those relationships becomes, the more viable and practical will be the results from this type of analysis. This model has been a first step in isolating the parameters and relationships in the economic sense. Further study is necessary to improve on the model and make it a better predictor of reality.

APPENDIX A

PIRS Forms and Data Format

Information enters the PIRS system by being typed on 80 column cards using the format on the following three forms. Data is transferred at Coast Guard Headquarters to Magnetic Tape using the format on pages following the PIRS report forms. Data contains 424 characters per record and is blocked three records to each block.

DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-4890 (10-74)	POLLUTION INCIDENT REPORTING SYSTEM (PIRS) *(DISCHARGE)*	INPUT TO PIRS PRE-EDIT 12210M

NOTE: 1. A - Alpha, N - Numeric (zero-fill), A N - Alpha Numeric
2. Columns 1 thru 16 same for both cards.

	FIELD	CARD COLUMN	DATA
RECORD ID	District	1-2 (N)	
	Sequence Number	3-7 (N)	
	Date of Incident	8 - 13 (N)	Yr. Month Day
	Transaction Code	14 - 16 (A)	ADD/COR/DEL
DISCHARGE	Card Number	17 (N)	1
	Time of Occurrence	21 - 23 (N)	Day of Week Hour of Day
	Location	24 - 33 (A/N)	
	State	34-35 (A)	
	Water Body	36 - 38 (N)	
	Source	39 - 41 (A/N)	
	Source Identifier	42 - 49 (N)	
	Cause	51-52 (A)	
	Operation	54-55 (N)	
	Material	56 - 59 (N)	
	Quantity	60 - 67 (A/N)	
	Affected Resources	69 - 74 (A/N)	
	Report Period Date	75 - 80 (N)	Yr. Month Day
	Card Number	17 (N)	2
	Wind Speed Direction	21 - 25 (N)	Knots ° True
	Sea Hgt Swell Direction	26 - 30 (N)	Feet ° True
	Current Speed Direction	31 - 35 (N)	Knots ° True
	Notifier	40-41 (A/N)	
	Anticipated Response	42 (N)	
	OPFAC Number	44 - 53 (A/N)	
	Report Period Date	75 - 80 (N)	Yr. Month Day

DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-4890A (10-74)	POLLUTION INCIDENT REPORTING SYSTEM (PIRS) (RESPONSE)	INPUT TO PIRS REPORT 12210M

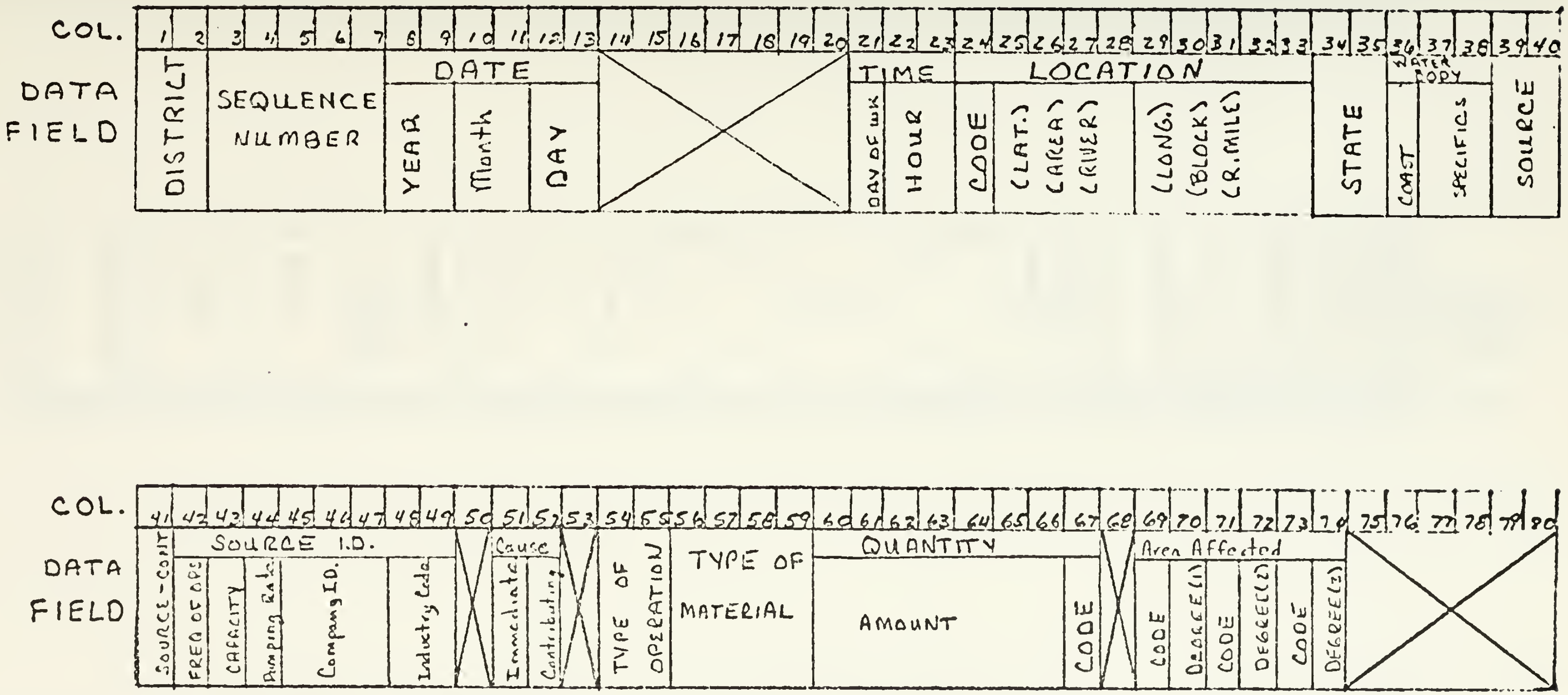
NOTE: 1. A - Alpha, N - Numeric (Zero-fill), A N - Alpha-Numeric, and N S - Numeric-Special Character.
2. Columns 1 thru 16 same on all cards.

	FIELD	CARD COLUMN	DATA
RECORD ID	District	1-2 (N)	
	Sequence Number	3 - 7 (N)	
	Date of Incident	8 - 13 (N)	Yr. Month Day
	Transaction Code	14 - 16 (A)	ADD/COR/DEL
RESPONSE	Card Number	17 (N)	3
	Removal Undertaken By (Party)	21 (N)	
	Equipment: Boom Materials	22 - 24 (N)	10's of feet
	Recovery Devices	25-26 (N)	Units
	Disposable Absorbents	27 - 30 (N)	Tons
	Recycleable Absorbents	31 - 33 (N)	Lbs.
	Burning Agents	34 - 36 (N)	Lbs.
	Dispersants	37 - 39 (N)	Gal.
	Herders	40 - 42 (N)	Gal.
	Sinking Agents	43-45 (N)	Lbs.
	Personnel (In man-days): CG Regular	55 - 57 (N)	
	CG Reserve	58 - 60 (N)	
	National Strike Force	61 - 63 (N)	
	EPA	64 - 66 (N)	
	Dept. of Defense	67 - 69 (N)	
	Commercial	70 - 72 (N)	
	Report Period Date	75 - 80 (N)	Yr. Month Day
	Card Number	17 (N)	4
	Personnel (Cont.): Volunteer	21 - 23 (N)	
	Other	24 - 26 (N)	
	Duration of Response	33 - 35 (N)	Days
	Amount Recovered	36 - 43 (A/N)	
	Cost of Cleanup: Total Cost	44 - 51 (N/S) $	
	Expenditures from Pollution Fund	52 - 58 (N) $	
	Reimbursements to Pollution Fund	59 - 65 (N) $	
	Reimbursements Pending	66 - 72 (N) $	
	Incomplete Reimbursement-Reason	73 (N)	
	Report Period Date	75 - 80 (N)	Yr. Month Day

DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-4890B (10-74)	POLLUTION INCIDENT REPORTING SYSTEM (PIRS) *(PENALTY ACTION)*	INPUT TO PIRS PRE-EDIT 12210M

NOTE: 1. A - Alpha, N - Numeric (zero-fill)
2. Columns 1 thru 16 same on all cards.
3. The following Card Numbers will be used when: No Action - Card 6, 1st action- Card 6, 2nd action - Card 7, 3rd action - Card 8, and 4th action - Card 9.

	FIELD	CARD COLUMN	DATA
RECORD ID	District	1-2 (N)	
	Sequence Number	3 - 7 (N)	
	Date of Incident	8 - 13 (N)	Yr. Month Day
	Transaction Code	14 - 16 (A)	ADD/COR/DEL
PENALTY ACTION	Card Number	17 (N)	
	No Coast Guard Action - Reason	21-22 (N)	
	Initiating Agency	26 (N)	
	Authority	27-28 (N)	
	Action Taken Against (Party)	29 (N)	
	Action Date	30 - 33 (N)	Month Day
	Referral to U. S. Attorney	34 (N)	
	Referral to COMDT/Other Agency	35 (N)	
	Action by U. S. Attorney	36 (N)	No - 0/Yes - 1
	Penalty		
	Penalty, Fine, or Settlement Assessed	39 - 43 (N)	
	Imprisonment	44-45 (N)	
	Suspension, Revocation, Probation	46 (A)	S/R/P
	Hearing or Trial	47 (N)	
	First Appeal	48 (N)	
	Second Appeal	49 (N)	
	Civil Action Appealed to U. S. Court	51 (N)	No - 0/Yes - 1
	Penalty, Fine, or Settlement Collected	53 - 57 (N)	
	Case Closed	58 (N)	
	Report Period Date	75 - 80 (N)	Yr. Month Day

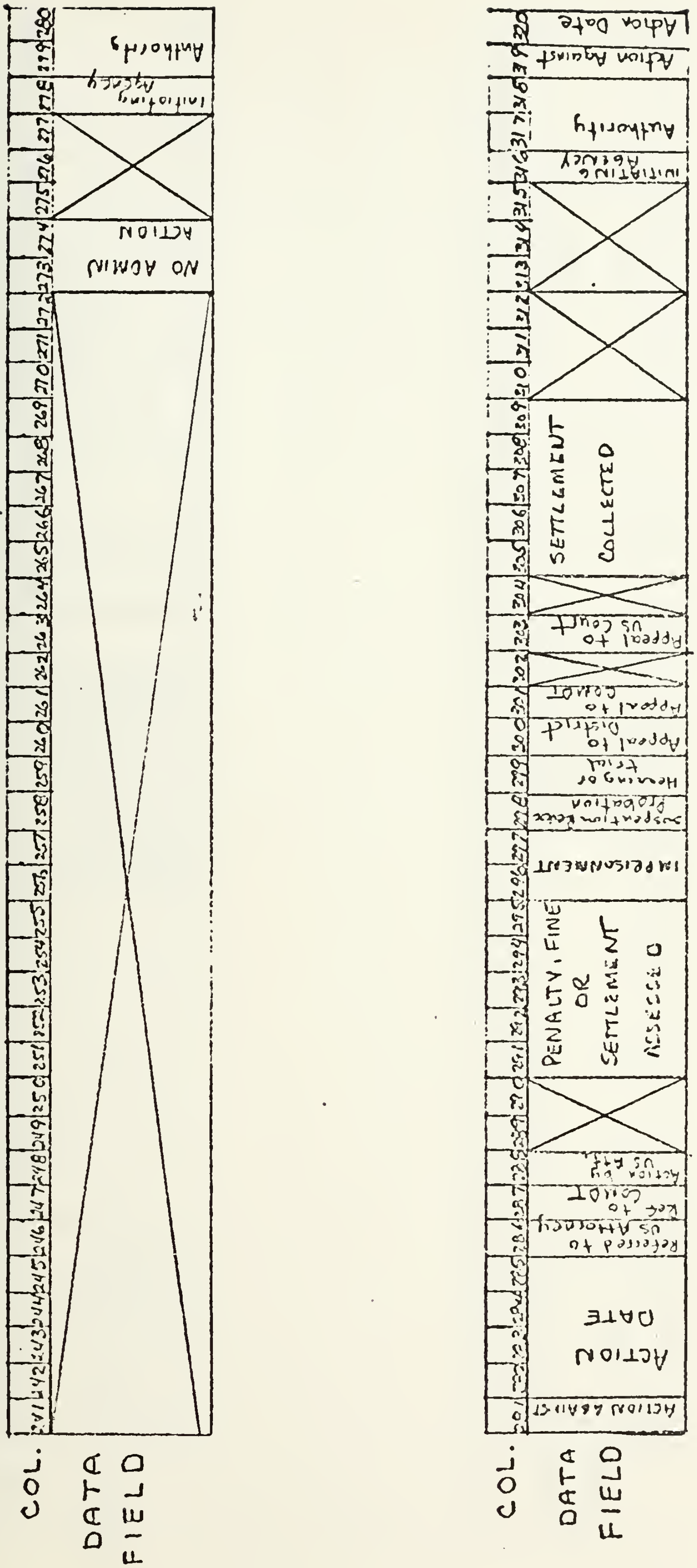

COL.
DATA FIELD
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
DISTRICT
SEQUENCE NUMBER
DATE
YEAR
Month
DAY
TIME
DAY OF WK
HOUR
LOCATION
CODE
(LAT.) (AREA) (RIVER)
(LONG.) (BLOCK) (R.MILE)
STATE
WATER BODY
COAST
SPECIFICS
SOURCE
COL.
DATA FIELD
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
SOURCE-CONT
SOURCE I.D.
FREQ OF OPS
CAPACITY
Pumping Rate
Company I.D.
Industry Code
Cause
Immediate
Contributing
TYPE OF OPERATION
TYPE OF MATERIAL
QUANTITY
AMOUNT
CODE
Area Affected
CODE
DEGREE(1)
CODE
DEGREE(2)
CODE
DEGREE(3)

DATA FIELD	COL.
BURNING AGENTS	121 122 123
DISPERSANTS	124 125 126
HEYDEYS	127 128 129
SINKING AGENTS	130 131 132
	133 134 135 136 137 138 139 140 141
CG REGULAR	142 143 144
CG RESERVE	145 146 147
NATIONAL STRIKE FORCE	148 149 150
EPA	151 152 153
DOD	154 155 156
COMMERCIAL	157 158 159
VOLUNTEER	160

DATA FIELD	COL.
WIND SPEED	81 82
WIND DIRECTION	83 84 85
SEA HEIGHT	86 87
SWELL DIRECTION	88 89 90
CURRENT VELOCITY	91 92
CURRENT DIRECTION	93 94 95
	96 97 98 99
NOTIFIER / Notifier	100
TIME LATE	101
Anticipated Response	102
	103 104 105 106
Cleanup Response	107
	108
BOOM MATERIALS	109 110 111
RECOVERY DEVICE	112 113
DISPOSABLE ABSORBENTS	114 115 116 117
REUSABLE ABSORBENTS	118 119 120

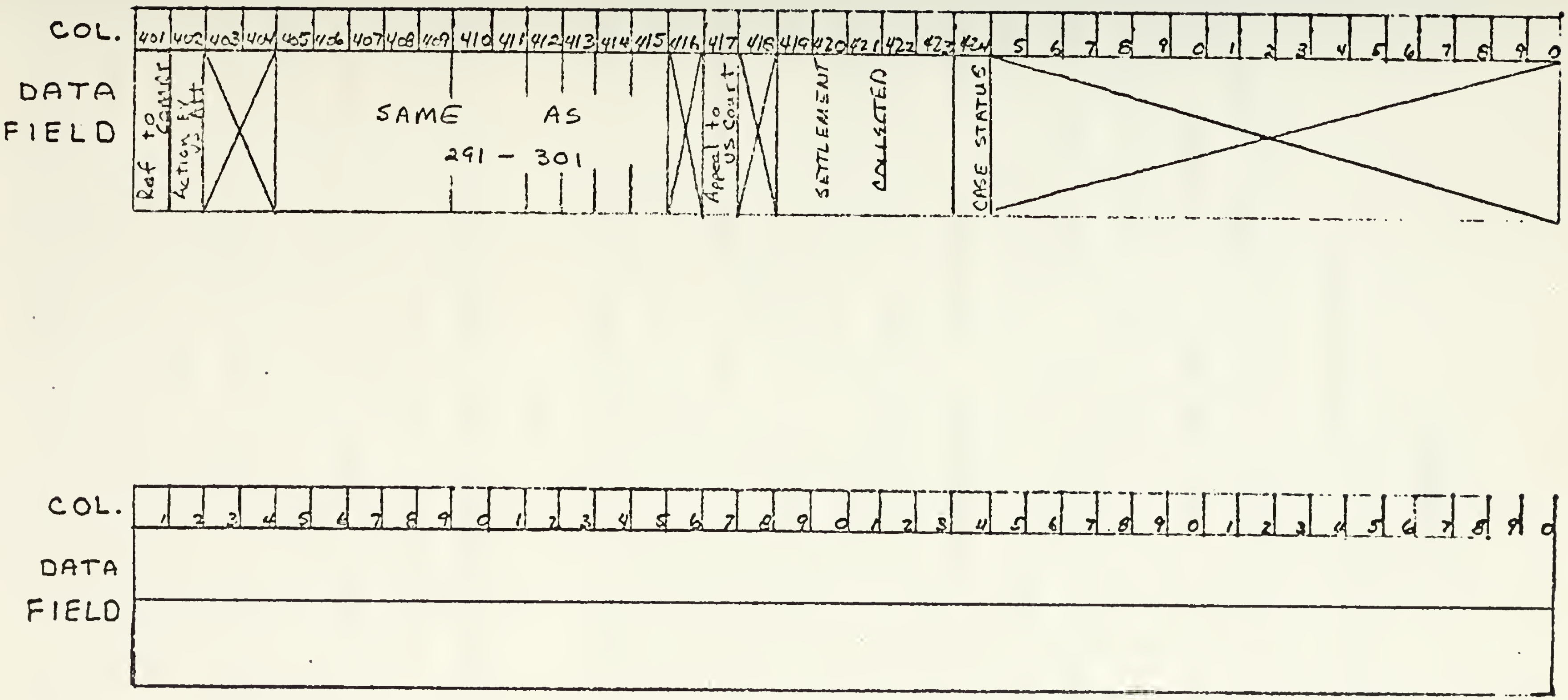
COL.	DATA FIELD
161–162	VOLUNTEER CONT
163–165	OTHER PERSONNEL
166–171	
172–174	DURATION OF RESPONSE
175–181	AMOUNT RECOVERED: AMOUNT
182	AMOUNT RECOVERED: CODE
183–189	TOTAL COST OF CLEANUP
190	COMPLETION
191–197	EXPENDITURES FROM POLLUTION FUND
198–200	REIMBURSEMENT TO FUND

COL.	DATA FIELD
201–204	CONTINUED
205–211	REIMBURSEMENTS PENDING
212	Reason for Incomplete Reimb
213–222	OPFAC
223–240	


COL.
DATA FIELD
NO ADMIN ACTION
Initiating Agency
Authority
COL.
DATA FIELD
ACTION AGAINST
ACTION DATE
Referred to US Attorney
Ref to Court
PENALTY, FINE OR SETTLEMENT ASSESSED
IMPRISONMENT
Hearing or trial
Appeal to District
Appeal to Court
Appeal to US Court
SETTLEMENT COLLECTED
INITIATING AGENCY
Authority
Action Against
Action Date

COL.	DATA FIELD
321–323	Action Date (cont)
324	Referred to US Attorney
325	Ref to COMDT
326	Action by US Att.
327–328	
329–333	Penalty, Fine or Settlement Assessed
334–335	Imprisonment
336	Suspension or execution prob
337	Hearing or trial
338	Appeal to Dist.
339	Appeal to COMDT
340	
341	Appeal to U.S. Court
342	
343–347	Settlement Collected
348–350	
351–353	
354–360	Same as 278 – 284

COL.	DATA FIELD
361–364	Same as 285 – 288
365–366	
367–377	Same as 291 – 301
378	
379	Appeal to US Court
380	
381–385	Settlement Collected
386–391	
392–400	Same as 273 – 286


COL.
DATA FIELD
401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0
Ref to Comm
Action by US Att
SAME AS 291 - 301
Appeal to US Court
SETTLEMENT
COLLECTED
CASE STATUS
COL.
DATA FIELD
1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0

APPENDIX B

Notes on an Oil Spill Cost Model

Any spillage of oil or chemicals into the waters of the world represents a loss of product to the economy. This loss is equal to the market value of the product lost. If the spill size, itself, is of sufficient magnitude to affect the aggregate economics of oil, the market value could change as a result of the spill. Estimates of the spillage that occurs each year run to approximately five million tons; however, this accounts for just a little over one per cent of the total volume of oil shipped by sea each year. It seems more likely, therefore, that a large spill would result in a local disruption rather than a market change in price. Simply stated, the loss associated with a given oil spill is:

$$\text{Loss} = kS$$

where k is the market price prevailing for the product and S is the size of the spill in gallons.

In addition to the loss of product, there will always be damage done to the aquatic environment and possibly spillover to the surrounding land areas. Many fractions of oil are soluble in water. When a spill occurs, these fractions will be taken into solution where the damage they inflict can not be reversed by simple removal of the visible product.

The environmental damage factor is complicated by the existence of short and longer range effects. An initial shellfish kill might be the predecessor of a longer range decrease in the commercial fishing value in an area. Little has been done in the way of rigorous studies to quantify the value of the environmental damage done by an oil spill. What is the total environmental cost of an oil spill? This is more difficult to assess than just adding up the cost of the product lost. Laws relating to the imposition of fines and civil penalties on discharges of oil state that the fine is to be based on the toxicity, size, dispersion characteristics, and degradability of the substance. It is the opinion of this author that the laws have left out the most important variable. The <u>location</u> of the spill is critical to the cost that is incurred. A given spill of size (S) and toxicity (T) with dispersion characteristics and degradability (C) will do more or less damage depending on the area it is going to affect. It seems reasonable to assume that the cost of environmental damage is, therefore:

$$D = S \cdot f(T) \cdot f(C) \cdot f(\text{location})$$

where S is a quantity and the other functions are all related to appropriate scale.

Toxicity and oil characteristics could be graded by a scale of 1 - 100, where increasingly toxic and persistent materials would be weighted by their relative hazard to the environment. The important step is to select an appropriate scale. The most toxic materials should have a scale value

proportional to the damage they cause which is proportional to the least toxic and the damage it causes.

Scaling these factors would result in a relative measure of the costs incurred due to the pollutant's potency and potential to do damage. An appropriate measure might be to express toxicity in terms of potential kill per concentration per unit area. That value could then be determined by surveying the system in which the spill occurs and multiplying the toxicity factor by the density of affected organisms and the area which they cover. One would then arrive at some measure of the actual damage suffered due to the introduction of the pollutant into the area.

It is the discussion of location value that holds the most potential for further study. Many of the tools and surveys needed for analysis of relative value by spill area already exist. The requirement for implementation of regional contingency plans for oil and hazardous substance spills has generated much of the needed information. The Army Corps of Engineers and the U.S. Geologic Survey have made detailed surveys of the water quality and coastal zone uses, and there are numerous local surveys done by local government and educational institutions which have charted the density and life cycles of marine organisms. Rather than summarize all the data available and the results which come to mind from intuitive formulation, it is more appropriate to list some of the major writings and publications which could lead the potential researcher to diverse and intriguing studies.

First, however, it is important to see the conceptual framework which has been used to understand the value of approaching the problem of cost determination from this point of view.

For a small area such as a bay, harbor, or a river running into the ocean, it is possible to determine the commercial value of the fisheries in that area, including the value of fish nurseries and particular organisms vital to the food chain of other commercial fisheries. Recreational values can be quantified in a rough sense, by taking a census of boaters and bathers who use the area and valuing that usage in man days used per unit area. Even property values and the value for commercial enterprises, such as restaurants utilizing the scenic value of the waterfront, can be roughly quantified to add to the determination of value of any particular water area.

As an example of the type of figures that can be derived by systematic and thorough analysis of an area, Dr. Beatrice Willard has estimated that one acre of saltgrass marsh has a potential value of over $85,000 per year (23). This figure includes its value as a commercial fishery, nursery for other fishes, watershed and flood control plain, and other quantifiable factors. Saltgrass marsh is a particularly productive and valuable water area. It is not as scenic, perhaps, as a jagged shoreline with spectacular surf, but in terms of biological value, it is certainly unrivaled.

Quantifiable costs, however, leave out important variables in the valuation of potential damage to a waterway or the surrounding shoreline. How can the uniqueness of a mangrove swamp or the home of an endangered species be valued? What is the value of an historical site? How can a price tag be placed on aesthetic beauty? These factors, for the moment, can not be adequately quantified.

The researcher must turn to another method of determining the value of the waters of the coastline that he is surveying. Ian McHarg, in his book, Design With Nature, presents an intriguing look at the valuation of the so-called "nonquantifiables." He approaches the act of land-use planning in an effort to minimize the total social cost while maximizing the social benefit. A similar technique could be applied to the valuation of our coastline.

It must be assumed that pollution of an area which is relatively more valuable than another is less desirable than pollution of a less valuable area. This might imply that if we know that incidents are going to occur, efforts should be employed which will seek to minimize the value lost by their occurrence. McHarg's method of determining relative value is to take a chart of the area under consideration and make extensive surveys to determine the variables that impact the value determination and split those variables into three zones. Each of the zones indicates some degree of value associated with that variable. For instance, historical value might be divided into the following three zones:

Zone 1. unique historical landmark -- of great importance

Zone 2. historical area -- no single unique landmark in danger from oil spills

Zone 3. little or no historical value -- value would be unaffected by oil spills.

This is a typical way in which each variable might be categorized. All variables are given relative values using similar scales. The most vulnerable zones are always Zone 1 and the least vulnerable, Zone 3. McHarg makes no attempt to give relative value to the variables, themselves; but if a particular variable or set of variables appears to be important, it may be broken down into more than one variable to give it extra weight. The Zones are then superimposed on the area charts and shaded according to increasing vulnerability. When all of the variables have been charted, the overlays are all placed together. The result is a composite which gives some indication of the relative value or, in this case, vulnerability to oil spills. It is important to note that the studies done by McHarg are primarily concerned with land-use planning. It is his technique which could have important applications for solving the oil spill cost problem.

Once a form of relative cost has been assessed, it can be used as a scaling factor to alter the toxicity, characteristics and size parameters of the cost function. A wholesale study might be expensive and possibly, even, inefficient if it were attempted on a highly formalized and national basis, but

the tolls for the regional manager to employ such a technique are right at his fingertips. The following annotated bibliography contains much of the information needed to do an adequate job of placing a relative cost on oil spills that occur and in helping the manager employ his resources to reduce the expected cost of oil spills in his area.

McHarg, Ian L., Design With Nature, (Published for the Museum of Natural History by Doubleday & Company, Inc., Garden City, New York, 1969).

This work defines the methodology and the ideology for the assessment of relative cost and values associated with geographic representations of land-use planning. The techniques and outlook can be extrapolated to the oil spill problem.

Isard, Walter and others, Ecologic-Economic Analysis for Regional Development, (The Free Press, New York, 1972).

"Some initial explorations with particular reference to recreational resource use and environmental planning." This book is more quantitative in its scope, but offers a similar analysis framework to McHarg's. It is applied to marine-related questions and contains a case study for the selection of a marina site in Plymouth-Kingston-Durbury Bay area in Massachusetts. It attempts to build a cost model for the ecological costs associated with the decision of placing a marina in the bay.

U.S. Coast Guard, A Suggested Development Plan for a Regional Contingency Plan Data Base, U.S. Gov't. Printing Office, April 1974. Prepared by the Office of R & D for the Office of Marine Environment and Systems.

This report suggests the strategy and format of a Regional Oil and Hazardous Substances Contingency Plan. The major contribution of this report to this subject is that if the plan is followed closely, the region will have a good grasp of the local knowledge and material available for doing a value survey of their area. It will, in itself, be a primary source for information and data.

> U.S. Coast Guard Region I, Multi-Agency Oil and Hazardous Materials Pollution Contingency Plan (Coastal), CCGDONE INSTRUCTION P5922,3A of 20 April 1972.

This is an example of a regional plan which contains many vital contacts for information relating to costing oil spills. Local agencies and industries involved in pollution control and commerce are listed and annotated.

> U.S. Army Corps of Engineers, National Shoreline Study, Regional Inventory Report, (For this study -- North Atlantic Region), 1971.

Volume I contains description and history of shoreline as well as current projects underway. Volume II of this study contains detailed maps of the shoreline with simple legends of ownership and principle use, as well as an indication of shoreline erosion and structure conditions. This could be used as a first source for a simple managerial planning model for spill containment and surveillance.

Certainly there needs to be a great deal of effort expended to have a vigorous, accurate concept of oil spill cost and potential cost, but the payoff is in an increased efficiency for pollution prevention and control effort. In addition, it would prove helpful in assessing appropriate

penalty levels for violators of the Oil Pollution laws and regulations.

APPENDIX C

Notes On the PIRS Data Base

The Pollution Incident Reporting System (PIRS) as revised in 1973 was used as the primary data base for this study. The data base contains a great deal of information in a highly usable format. The comments which follow are offered as the impressions of a user of PIRS and suggestions for improving the existing system. Issues that will be discussed are:

1. Technical aspects of the data structure
2. Questions relating to the usefulness of the data

The data contained on magnetic tape contained numerous errors. The error rate was not high; however, for this analysis a number of data fields had to be rejected due to errors in numeric fields. Errors which could be easily detected seemed to be restricted to certain fields whose removal did not affect this study. Questions relating to a more comprehansive study, such as an oil spill simulation model would require the use of those fields for usable results to be generated.

The most common of this type of error were:

1. Location: Latitude and Longitude were expressed as 35-3N instead of 35-18. Inclusion of alphanumeric characters into the field either causes the data to be rejected or makes the data inaccurate for use.

2. Quantity: There were two common errors in this and other fields where numerical variables were entered.

a. Zeros (0) and the letter "O" were interchanged causing the same error as in (1) above.

b. Figures were not right-justified in the field. The result was figures which were too large or, in some cases, when the code following the value was also moved left, the error similar to (1) above occurred.

3. Quantity removed: A more subtle error entered into this field. In a number of instances, the quantity removed was significantly greater than the quantity spilled (e.g., a spill of less than ten gallons had more than a million gallons removed). This error could have resulted from misplacement of the data in the field, or, more subtly, differing opinions as to the meaning of the data field could have been employed.

4. Fields related to penalty action administration were not used as extensively for this study; however, similar errors may likely exist in those fields.

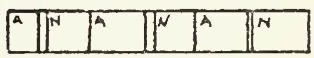
These data errors point to possible problem areas in the collection and encoding of the data. A first hunch was that the data resulted from key punching errors. Contact with the Twelfth Coast Guard District ADP office brought out the fact that data is verified before being submitted to batch processing in headquarters. This does not rule out error, but indicates that similar errors are being made on the verification punch to those that occur on initial punching.

The form of the data arriving at the encoding point may account for this type of error. The key punch operators probably have very little idea of the meaning of the coded data they receive from the MEP office. If a field is defined as containing alphanumeric data, it is difficult to know whether to punch a zero or an "O" if the character on the form is "O".

The person filling out the forms must be meticulous to differentiate between letters and numbers. PIRS has settled on the convention of putting slashes through the number and this convention should be known expressly to the operators.

The form, itself, may be part of the problem. If the fields were broken down into their component parts, the errors might not be as likely to occur. As shown in the figure below, the data fields for quantity and affected resources might be broken down into their component parts.

Quantity (coded) 60-67(N)(A) 

Affected Resources 69-74(A)(N) 

Ad additional problem area occurs when the person entering the data does not right or left justify the data on the form, resulting in strange results in some fields.

These errors are probably well known to the users and designers of the PIRS system, but the data base still suffers from their existence. The time required to track down these errors is not productive to the research, and the research suffers from the need to discard whole data fields from the

analysis. It is necessary to either prepare a complex debugging program for the data base or to spend effort on improving data preparation and transmittal to the central data base.

From the standpoint of the researcher tapping into a relatively untried data base, the temptation was to be skeptical of the results of any analysis. It would have been easy to accept without question the data as it existed on the computer tapes, since it is a well known fact that data undergoes a miraculous change from subjectivity and estimation to objectivity and accuracy when it is coded as magnetic spots on a reel of computer tape. But working with the data raised serious, persistent questions as to its accuracy. To be more precise, the questions relate to whether or not the results that come from the data are really valid. For instance, the rate of unknown or unentered information in certain data fields ranges up toward 50% of the total. With over 25,000 pieces of data, the temptation is to assume that the missing data has the same distribution as does the existing information. This may very well be true for certain data fields but could be totally wrong for others. If errors are consistently made at certain levels of data, it could radically distort the distributions from their actual shape. Some of the items that intuitively seemed inconsistent were:

1. Location: A plot of the latitude and longitude for the Twelfth Coast Guard District for one quarter of 1974

showed a large number of incidents which occurred outside of the district or on dry land.

2. Quantity: This is often a subjective determination with a high degree of variability. The eighth position on the data field could be expanded to include some measure of "degree of confidence" in the estimate, such as:

a. A quantity known for sure (by measurement or metered data) gallons

b. B quantity estimated (estimate is considered good -- person qualified to judge the amount) gallons

c. C quantity estimated (fair estimation) gallons

d. D quantity estimated (poor or unknown accuracy) gallons

e. E-H similar to A-D for pounds

f. U Unknown

g. Y Potential

3. Notifier: When the notifier was listed as a commercial source, there was some question as to whether it was from the source or reported by a neighboring industry or passing vessel.

The second part of this field is used to indicate the time elapsed between occurrence of the spill and notification or discovery. The results for the Twelfth Coast Guard District (quarter 1 1974) indicate that the vast majority of spills are discovered and reported immediately. Intuitively, there remains some question as to that fact. The point is, that studies of certain data fields might produce data vastly different from that which is reported.

4. Cost of Cleanup: Cost relating to use of federal, state and local government personnel and equipment does not enter into the determination of many spill's costs. The inclusion of those costs would be helpful in determining the cost versus size function for oil spills. The results might be very informative if government resources were costed at their fair market value.

5. Amount Recovered: In some cases the amount recovered exceeds the spill size. This indicates that errors in data recording or reporting philosophy are occurring. If a spill from a grounded tanker amounts to half a million gallons, but removal operations recover twenty million gallons before it enters the water, the reporter must decide whether to report removal of the oil which entered the water or the total recovered. It is important to distinguish between those figures when they are entered into the system. This might call for an additional data field which is called "total product recovered by operations."

6. Degree of Impact: The range of degree of impact with spill size was slight. The average minor spill did negligible damage, the average moderate spill slight damage, and the average large spill slight to moderate damage. This seems inconsistent with the objective of the oil pollution control program. If spills aren't doing much damage, why should they be controlled!

The use of any computerized data base without proper control and some form of feedback to the operating level is

asking for enormous problems with the system and the results taken from analysis of the data. It is understood by the author that a feedback report is being prepared for Coast Guard District Offices. It is hoped that the reports will be used and passed on to all operating units to be used as a source of information and as the impetus to study the reporting system itself.

The manager who receives the feedback report should ask himself two simple questions:

1. Does this report reflect my perception of the oil spill problem?

2. If it doesn't, what's the difference between my perception and what is coming out on this report?

Discrepancies in the perceived oil spill problem and the feedback reports indicate that what is being sent to headquarters is not being interpreted in the same way by various units. These discrepancies can be tracked down and the reporting process can be altered to more accurately reflect the oil pollution problem within the local area. If every district points up discrepancies and attempts to make the reports reflect the actual pollution situation in their district, the entire data base will be strengthened. It will become more accurate, more standardized, and of more use to managers and researchers alike.

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Economic effects of enforcement variables on commercial oil pollution control strategy.